

1 "X-Ray Topographic System"

2

3 This invention relates to an X-ray topographic
4 system for use in examining crystal structures, for
5 example silicon single-crystal wafers or boules for
6 use in the production of semiconductors.

7

8 Background to the Invention

9

10 It is known to examine, for example, silicon wafers
11 by means of X-rays to detect flaws such as slip
12 bands which are nucleated during the rapid thermal
13 annealing process. Such examination has hitherto
14 been carried out by means of a Lang camera making an
15 exposure on film. Prior art processes have suffered
16 from a number of disadvantages, including the large
17 size of the camera system, limitations on the size
18 of the wafer which can be examined, and long
19 processing times (typically about one hour for an 8"
20 or 200 mm wafer).

21

1 One object of the present invention is to provide an
2 X-ray topographic system which is capable of
3 examining large samples, typically up to 300 mm
4 diameter, and carrying out examinations rapidly,
5 typically 5 to 15 minutes.

6

7 Summary of the Invention

8

9 Accordingly, the present invention provides an X-ray
10 topographic system comprising:

11 an X-ray generator for producing a beam of
12 X-rays directed towards a sample location; and
13 a detector positioned to receive X-rays
14 deflected by a sample at the sample location, the
15 detector comprising an electronic X-ray detector
16 having an array of pixels corresponding to the beam
17 area.

18

19 The X-ray beam may have a relatively large
20 divergence of up to 20 milliradians.

21

22 In one form of the invention, an X-ray optic is
23 interposed between the X-ray generator and the
24 sample location, and is arranged to receive said
25 beam and to transmit the X-rays as a substantially
26 parallel beam.

27

28 In an alternative and higher resolution form, no X-
29 ray optic is used, and any unacceptable doubling of
30 the image is removed or compensated by software.

31

1 The detector may be positioned to receive deflected
2 X-rays transmitted through the sample.

3 Alternatively, the detector may be positioned to
4 receive deflected X-rays reflected from the sample.

5

6 The X-ray generator is preferably adapted to produce
7 a source spot size of 100 μm or less and preferably
8 has an exit window less than 20 mm from the target.

9

10 Preferably, the system resolution is about 25 μm or
11 better and the detector is located 5 - 10 mm from
12 the sample location.

13

14 The X-ray optic is preferably a lobster eye optic
15 comprising a number of X-ray reflective plates set
16 at a slight angle from each other so that the output
17 beam is substantially parallel. Typically, the
18 plates are about 150 μm thick and are coated with
19 gold.

20

21 The detector is suitably a charge coupled device,
22 most preferably a digital CCD.

23

24 The present invention also provides an X-ray
25 topographic apparatus comprising an X-ray
26 topographic system as defined above, stepping means
27 for producing relative stepwise motion between the
28 system and a sample to be inspected, the step size
29 being a function of the beam area and spectral
30 profile, and image processing means for reading out
31 the pixel data of the detector between successive
32 steps.

1 Other features and advantages of the present
2 invention will be apparent from the following
3 description and from the appended claims.

4

5 Description of Preferred Embodiments

6

7 Embodiments of the invention will now be described,
8 by way of example only, with reference to the
9 drawings, in which:

10

11 Fig. 1 is a schematic side view illustrating one
12 system embodying the invention;

13 Fig. 2 illustrates the operation of the system of
14 Fig.1 ;

15 Fig. 3 shows one component of Fig. 1 in greater
16 detail;

17 Fig. 4 is a schematic representation of an
18 apparatus incorporating the system of Fig. 1;

19 Fig. 5 illustrates an alternative form of
20 apparatus;

21 Fig. 6 illustrates a modified system without an
22 x-ray optic;

23 Fig. 7 is an example of an image obtained by a
24 system embodying the invention;

25 Fig. 8 is a flow chart of an algorithm used in
26 one form of the invention;

27 Fig. 9 illustrates geometric coordinates used in
28 combining images;

29 Fig. 10 is a flow chart of an algorithm used in
30 combining images; and

31 Figs. 11 and 12 are examples of combined images.

1 Embodiment of Wafer Inspection System

2

3 The embodiment of Figs. 1 to 3 is particularly
4 suitable for slip band detection in Si wafers up to
5 300 mm diameter.

6

7 Referring to Fig. 1, a silicon wafer 10 is inspected
8 by a topographic system comprising an X-ray
9 generator 12, an X-ray optic element 14, and a
10 detector indicated generally at 16.

11

12 The X-ray generator 12 is most suitably the
13 Microsource® X-ray generator from Bede plc of
14 Bowburn, Co. Durham, which is the subject of WO
15 98/13853. Briefly stated, the Microsource®
16 generator comprises an evacuated X-ray tube with
17 external focussing coils arranged to produce a spot
18 X-ray source on the target of 100 μm or less, and a
19 configuration where the X-ray exit window is within
20 5 - 10 mm of the target. The Microsource® generator
21 is particularly suitable for use in the present
22 invention, since it enables an X-ray optic to be
23 positioned close to the small target spot while at
24 the same time delivering a narrowly diverging beam
25 to the optic.

26

27 The X-ray optical element 16 is any suitable element
28 which will accept slightly divergent rays from the
29 generator 12 and provide as output an area of
30 parallel X-rays. The preferred element, as used in
31 this embodiment, is a "lobster eye" optic; X-ray

1 optics of this type have been described in the prior
2 art, but only in relation to use in X-ray astronomy.

3

4 As seen in Fig. 3, the lobster eye optic 14
5 comprises a series of flat plates 18 acting as
6 specular reflectors and mounted to be accurately
7 radially divergent from a point half way between the
8 point source and the mid point of each reflector.

9 In the preferred embodiment, the X-rays are copper K
10 radiation, the plates 18 are gold coated and are
11 about 150 μ m thick, 6 x 30 mm in area, and with 80%
12 average reflectivity. Using a total of fourteen
13 plates, which is the practical maximum that can be
14 accommodated with the above thickness, gives a
15 theoretical gain of $1 + 14 \times 0.8 = 12$ approximately.

16

17 Reverting to Fig. 1, the output from the lobster eye
18 optic 14 is a substantially parallel beam 20 which
19 is incident on the wafer 10. The undeflected beam
20 20a is intercepted by a beam stop 22. The deflected
21 beam 20b is incident on an electronic detector
22 element 24 which will be described below.

23

24 More specifically, the beam 20 has a divergence of
25 about 2 mr and is segmented into a number of
26 stripes, about 30 mm long. Each stripe is
27 polychromatic and gives rise to a $K\alpha_1$, $K\alpha_2$ stripe on
28 the image (see Fig. 2). Hence the image from one
29 stripe will be doubled.

30

31 In the usual method of Lang topography, the specimen
32 and the photographic plate are translated together

1 through the beam. A defect is seen twice, once by
2 the $\text{K}\alpha_1$ beam and later, after the plate has
3 translated, by the $\text{K}\alpha_2$ beam. Because the distance
4 from the specimen to the film is at least 50 mm for
5 a large wafer, and the divergence between $\text{K}\alpha_1$ and
6 $\text{K}\alpha_2$ is about 2.5×10^{-3} , the image is doubled (by 50
7 $\times 2.5 \times 10^{-3} = 0.125$ mm) and a slit, rather than just
8 a stop, is used to select only the $\text{K}\alpha_1$ beam.

9
10 In the present arrangement, the image is not doubled
11 when the wafer 10 is static; the $\text{K}\alpha_2$ is simply of
12 weaker intensity, and other components from
13 Bremsstrahlung are also there without any image
14 multiplication. This is actually a spectrally-
15 reduced segment of a white radiation topograph.

16
17 If now we translate the wafer 10 by a step, we will
18 get a faithful image of the part of the specimen
19 that is now struck by the beam. With a film
20 detector this would of course be superimposed on the
21 first image. However, by using an electronic
22 detector element 24 it is possible to store the
23 images from successive steps electronically to
24 produce an image for the entire wafer 10.

25
26 As long as all of the wafer 10 is scanned uniformly
27 by all of the beam, it does not matter what is the
28 intensity profile in the beam. The basic
29 requirement for the optic 14 is that as much
30 intensity as possible is reflected/scattered
31 parallel to the original direct beam.

1 It is extremely desirable that the generator 12
2 provides a "point" (as discussed below) source. A
3 line source perpendicular to the plane of Fig. 2
4 will give coma in the same direction, and a line
5 source parallel to the plane of Fig. 2 and to the
6 wafer will give doubled images from the $\text{K}\alpha_1$, $\text{K}\alpha_2$
7 components.

8

9 Turning to questions of resolution and source size,
10 the usual equation for resolution, d , applies:

11
$$d = hb/a$$

12 where a and b are as defined in Fig. 2, and h is the
13 source dimension perpendicular to the Figure. In the
14 arrangement of Fig. 1, the dimensions of the
15 Microsource® X-ray source determine a as no smaller
16 than 75 mm, and b could readily be 15 mm.

17

18 X-ray topographers have customarily striven to meet
19 a target of 1 μm resolution, which may be desirable
20 for academic research but involves very long (days)
21 exposure and processing time. Since the potential
22 exposure reduces as the square of resolution, huge
23 gains can be made by relaxing the target resolution.
24 For use in the inspection and quality control of
25 semiconductor materials, it is necessary to see
26 isolated dislocations, but not the details of their
27 interactions. We have concluded that a resolution
28 of 25 μm is ample for this, and indeed up to 100 μm
29 could be usable.

30

1 Aiming for 25 μm resolution implies an X-ray source
2 spot of 125 μm . Considerations of coupling to an
3 optic could limit the spot size to 100 μm which in
4 the Microsource® generator could be run at 100W, and
5 give a resolution of 20 μm on the detector screen.

6

7 There is still a risk of image doubling from the $\text{K}\alpha$
8 doublet, since the beams will still diverge from a
9 defect position by 10^{-3} on their way to the detector.
10 However, if the detector is within 10 mm of the
11 wafer the blurring will only be 25 μm , which is
12 acceptable, and it should be possible to achieve a
13 distance of 2-5 mm between sample and detector.

14

15 For the above-described embodiment and benchmark
16 measurements, we have calculated that the exposure
17 time for examining a 8" (200 mm) Si wafer, using 100
18 W on a Cu target, would be in the region of 5-10
19 minutes. In contrast, a known system uses 2.5 m
20 between source and wafer with image capture on film,
21 15 kW source power, and 1 hour exposure time. It
22 also requires photographic film processing.

23

24 Considering now the detector 16, the basic
25 requirement is a detector which gives an electric
26 signal output of received X-ray intensity in a pixel
27 array. The preferred detector is a digital CCD
28 detector in a rectangular configuration, e.g. 2000
29 by 200 pixels. Such detectors are available with a
30 resolution from 24 down to about 7.5 μm . The use of
31 a detector of this aspect ratio allows the detector

1 to be placed very close to the wafer. A less
2 sophisticated alternative is the Photonic Science
3 Hires detector which can be configured to give
4 30 μm resolution over about 12 x 15 mm, or 15 μm
5 resolution over 6 x 7.5 mm.

6

7 Embodiment of Wafer Inspection Apparatus

8

9 Turning now to Fig. 4, there is schematically
10 depicted an apparatus, incorporating the foregoing
11 system, for inspection of wafers. The apparatus 40
12 includes an XY table 42 driven along orthogonal axes
13 by servomotors (not shown) in known manner, a
14 Microsource® controller 44, an interlock controller
15 46, and a servomotor controller 48. The apparatus
16 40 is of compact dimensions, typically about 650 mm
17 wide by 750 mm high.

18

19 Embodiment of Boule Inspection by Reflection

20

21 The invention as thus far described operates in
22 transmission. It may equally be used in a
23 reflection mode, either with wafers or, as
24 illustrated in Fig. 5, with a boule 50. A Si boule
25 may typically be 300 mm diameter by about 1 m
26 length. The entire boule or selected parts only may
27 be inspected by providing servomotor drives to
28 produce stepwise relative motion between the boule
29 50 and the inspection system 10,12,14 in rotation
30 and axially. Again, the requirement is to acquire a
31 digital representation by stepping the detector
32 across the area of interest.

1 It will be understood that the image data at each
2 step is read out and used to build up an image of
3 the entire area inspected. Typically, the value for
4 each pixel will be stored in a corresponding memory
5 location until the entire image can be displayed on
6 a screen or printed. It may be necessary to use
7 commercially available image processing software to
8 normalise image intensities and to merge the images
9 from the separate steps together.

10

11 Embodiment of System without X-ray Optic

12

13 Turning now to Fig. 6, a modified form of the
14 present invention will be discussed. Fig. 6 is
15 similar to Fig. 1 and similar parts are denoted by
16 like reference numerals. In Fig. 6, however, the X-
17 ray optic such as lobster eye optic 14 is omitted.
18 This has the result that the X-ray beam 20 reaching
19 the sample 10 is more divergent than in the previous
20 embodiments, and the radiation deflected by the
21 sample has a broader spectral range. When an optic
22 is used the divergence can in practice be limited to
23 about 2 mr. When no optic is used, the divergence
24 depends on the nature and operating conditions of
25 the X-ray source, but typically a relatively large
26 divergence of up to 20 mr may be used.

27

28 In one example of such an arrangement, a
29 Microsource® generator was used with a copper anode.
30 The x-ray imaging system was a Photonic Science
31 imager with 512 x 512 pixels each with a nominal
32 size of 30 x 30 μm . This was connected to a 700 MHz

1 Pentium III based PC with 128 Mbytes of RAM, and
2 using a PCVision frame grabber.

3

4 Fig. 7 is a representation of one image obtained
5 from the arrangement of Fig. 6 examining an edge
6 region of a silicon wafer. This shows two
7 diffraction streaks from the 115 glancing incidence
8 Bragg reflection from a Si(001) sample. The left
9 and right streaks are respectively $K\alpha_1$ and $K\alpha_2$
10 diffraction streaks. The streaks are curved at the
11 bottom due to the curved edge of the sample. A
12 defect is visible about 2/3 of the way down from the
13 top of the $K\alpha_1$ streak as a bright white region.

14

15 In the embodiments of Figs. 1 to 5, the $K\alpha_1$ and $K\alpha_2$
16 diffraction streaks, due to the presence of the
17 optic, are sufficiently close together to be treated
18 as a single image for most purposes. In the present
19 embodiment this may be possible for some less
20 critical applications, but if not then the images
21 produced by the detector can be manipulated by
22 software.

23

24 For any known specimen-detector distance there is a
25 known divergence of the $K\alpha_1$ and $K\alpha_2$ beams. This in
26 effect gives a slight magnification of the image,
27 and can be corrected completely by demagnifying the
28 image in one dimension only (in the incidence
29 plane). This removes completely the effects of the
30 spectral distribution upon the resolution, which
31 thus becomes limited only by the detector
32 resolution, which is expected to improve with

1 progress in the semiconductor technology, and can be
2 sub-micron. However, this correction will not be
3 possible where the specimen is not reasonably
4 planar.

5

6 As an alternative, or where there is a bent or
7 distorted specimen, the $K\alpha_1$ and $K\alpha_2$ images can be
8 separated in the software and processed to maintain
9 resolution and intensity, as described below.

10

11 The foregoing description has assumed a single
12 exposure at each step of the sample. However,
13 currently available electronic X-ray detectors are
14 not sufficiently sensitive to allow such operation,
15 which would result in an unacceptable signal to
16 noise ratio. It is convenient to use a detector
17 such as a CCD detector operating in a conventional
18 raster scan such as 525 lines at 60 Hz or 625 lines
19 at 50 Hz. In this case, a significant number of
20 frames of the same sample area will have to be
21 integrated, i.e. a cumulative sum taken for each
22 pixel. With available technology it may be
23 necessary to integrate between 10 and 2000 frames
24 before stepping to the next area of the sample.

25

26 Examples of Software

27

28 There now follows one example of software by which a
29 number of frames in a wider format can be
30 integrated.

31

1 Integrating Image
2
3 This example employs an algorithm as shown in Fig. 6
4 and further described as follows (text in a bold
5 font refer to variables defined in the program
6 source code):-
7
8 1. The routine is initialised by creating a 32-bit
9 floating point image (**im_expose**) and an 8-bit (byte)
10 image (**im_temp**). The X-ray imaging system, assumed
11 to be connected to channel 0 of the PCVision card,
12 is selected as the video source.
13
14 2. Acquire (snap) a single frame from the X-ray
15 imaging system into the byte image, **im_temp**.
16
17 3. If the gray scale exposure type is selected
18 continue to step 4. If the binary threshold
19 exposure type is selected, convert the current
20 frame, **im_temp**, to a two-level (binary) image.
21 Pixel values in **im_temp** below the specified
22 threshold limit are set to zero (black) whereas
23 pixel values above the threshold value are set to
24 255 (white).
25
26 4. Add the current frame, **im_temp**, to the
27 integrated image, **im_expose**. A 32-bit floating
28 point image is used to store the integrated image so
29 as to avoid overflow problems. The image **im_temp** is
30 added to **im_expose** on a pixel-by-pixel basis. The
31 resultant image is multiplied by a scaling factor,
32 which in this case is set equal to 1.0.

1 5. Repeat steps 2-4 until the specified number of
2 frames, designated by the **Frames** variable, is
3 integrated.

4

5 6. Finally, convert the 32-bit floating point
6 image **im_expose** to an 8-bit byte image. In order to
7 convert between 32-bit and 8-bit image formats the
8 pixel values are scaled to map to the value range 0
9 to 255. This scaling can be achieved in three ways:
10 a) by dividing **im_expose** by the number of frames
11 integrated. b) automatically based on the minimum
12 and maximum pixel values and c) by adding an offset
13 and multiplying by a scale factor. In the latter
14 case, values that are still outside the 0 to 255
15 range are clipped. Pixel values less than 0 are set
16 equal to 0 while those greater than 255 are set to a
17 value of 255.

18

19 7. Save the final 8-bit integrated image to a disk
20 file with a specified name.

21

22 8. Display the integrated image in the main
23 program window.

24

25 Combined Integrated Images

26

27 The integrated images acquired according to the
28 algorithm described in the previous section contain
29 K α 1 and K α 2 diffraction streaks respectively from
30 positions (χ_1, γ_1) and (χ_2, γ_2) on the sample. The
31 Tile command combines a distribution over an
32 extended region.

1 In order to understand the Tile algorithm, we must
2 define the coordinate spaces used to describe the
3 location of pixels within an image and the location
4 and size of a rectangular region of interest (RROI)
5 within an image. It is also important to define the
6 transformation that maps a spatial coordinate (x, y)
7 on the sample to a pixel coordinate in an image or
8 RROI.

9 Referring to Fig. 7, the origin of an image has the
10 coordinates $(0, 0)$ and refers to the pixel at the
11 top, left-hand corner of the image. The horizontal
12 side of the image is denoted by X and the vertical
13 side of the image by Y . Hence, the pixel at the
14 bottom, right-hand corner of the master image has
15 the coordinates (X, Y) .

16

17 The origin of a RROI has the coordinates (x, y)
18 relative to the origin of its parent image. The
19 horizontal extent of an RROI is denoted by dx and
20 the vertical extent by dy . Hence, the pixel at the
21 bottom, right-hand corner of an RROI has the
22 coordinates $(x+dx, y+dy)$ relative to the origin of
23 its parent image.

24

25 Fig. 7 shows the relationship between the
26 coordinates of an image and an RROI. The equations
27 used to transform between world coordinates (x, y)
28 and RROI coordinates (x, y) within an image expressed
29 as follows

30
$$x = (x - x_0)/dx$$

31
$$y = (y - y_0)/dy$$

32

1 where (x_0, y_0) is the origin expressed in world
2 coordinates and dx and dy are the pixel dimensions
3 of the X-ray imaging camera in the x -(horizontal)
4 and y -(vertical) directions, respectively. Here we
5 have assumed that the senses of the x - and y -
6 directions are identical to those within the image.
7 The pixel coordinates for both images and RROI's are
8 arranged such that the x -ordinate increases from
9 left to right (horizontal). The y -ordinate
10 increases from top to bottom (vertical).

11

12 The algorithm employed by the Tile command is shown
13 in Fig. 8 and further described as follows (text in
14 bold font refer to variables defined in the program
15 source code):

16

17 1. The routine is initialised by creating a 32-bit
18 floating point image (**im_tile**) and rectangular
19 region of interest (RROI) within this image
20 (**rroi_tile**). The X-ray imaging system, assumed to
21 be connected to channel 0 of the PCVision card, is
22 selected as the video source.

23

24 2. From a user selected .ini file, read the origin
25 (**OriginX**, **OriginY**) and horizontal and vertical pixel
26 sized, denoted by **ScaleX** and **ScaleY**, respectively in
27 world coordinates.

28

29 3. Read the position (**x**,**y**) and horizontal and
30 vertical dimensions denoted **dx** and **dy**, respectively
31 from the .ini file. These values are in world units
32 (typically mm). Also read the name of the

1 integrated image file associated with this world
2 position.
3
4 4. Create a temporary 8-bit image, **im_temp**, and
5 read the file obtained in step 3 into this image.
6
7 5. Create RROI within the temporary image,
8 **rroi_temp**. The starting position and size of
9 **rroi_temp** is selected to include one, or both, of
10 the diffraction streaks.
11
12 6. Subtract a constant value from **im_temp** on a
13 pixel-by-pixel basis, the constant value being the
14 average pixel value within a region far from either
15 one of the diffraction streaks, i.e. the background
16 pixel value.
17
18 7. Move the RROI **rroi-tile** according to equation
19 1.1. Adjust the size of the **rroi.tile** to match that
20 of **rroi_temp**.
21
22 9. Add the RROI, **rroi_temp**, to the topograph RROI,
23 **rroi_tile**. A 32-bit floating point image is used to
24 store the topograph so as to avoid overflow
25 problems. The image **rroi_temp** is added to **rroi_tile**
26 on a pixel-by-pixel basis. The resultant image is
27 multiplied by a scaling factor, which in this case
28 is set equal to 1.0.
29
30 10. Delete the temporary image, **im_temp**, and RROI,
31 **rroi_temp**.
32

1 11. Repeat steps 3-9 until all integrated image
2 files in the user selected .ini file have been
3 processed.
4
5 12. Convert the 32-bit floating point image **im_tile**
6 to an 8-bit byte image. In order to convert between
7 32-bit and 8-bit image formats the pixel values are
8 scaled to map to the value range 0 to 255. This
9 scaling can be achieved in three: a) by dividing
10 **im_expose** by the number of frames integrated. b)
11 automatically based on the minimum and maximum pixel
12 values and c) by adding an offset and multiplying by
13 a scale factor. In the latter case, values that are
14 still outside the 0 to 255 range are clipped. Pixel
15 values less than 0 are set equal to 0 while those
16 greater than 255 are set to a value of 255.
17
18 13. Save the final 8-bit integrated image to image
19 to a disk file with a specified name.
20
21 14. Delete the image **im_tile** and associated RROI,
22 **rroi_tile**.
23
24 15. Finally, display the integrated image in the
25 main program window.
26
27 Examples of Expose and Tile
28
29 Figs. 11 and 12 show selected reflection topographs
30 created using the Expose and Tile commands described
31 above. All of the topographs have been inverted to
32 facilitate comparison with conventional X-ray

1 topography. White regions are those areas that
2 weakly diffract X-rays whereas black regions are
3 those that diffract strongly.

4

5 Figs. 11 and 12 show a reflection topograph produced
6 using both the $K\alpha 1$ and $K\alpha 2$ diffraction streaks.
7 Integrated images were collected at a horizontal
8 interval of 0.1 mm with 250 frames integrated in
9 each image (this corresponds to an acquisition time
10 of about 12 secs per image). A pixel size of 0.28
11 mm was used instead of the nominal value of 0.30 mm
12 as this resulted in the sharpest topographs.

13

14 When acquiring the integrated images used to create
15 the topograph shown in Fig.11, the sample was
16 accurately aligned such that the diffraction streaks
17 were vertical. This is not the case with the
18 integrated image shown in Fig.12. In this case, we
19 immediately see that the diffraction streaks are
20 inclined a few degrees away from the vertical
21 direction. This was due to the tilt (χ -axis) of the
22 sample being improperly adjusted with respect to the
23 incident X-ray beam. For flat samples it is easy to
24 align the sample such that the diffraction streaks
25 are vertical. However macroscopically bent or
26 distorted sample may lead to diffraction streaks
27 that are inclined to the vertical direction. If
28 this is indeed the case, the final topograph will be
29 blurred or contain *ghost* images due to the $K\alpha 1$ and
30 $K\alpha 2$ radiation not overlapping. A rather contrived
31 example of this effect is shown in Fig.12. This

1 topograph was created using both the $\text{K}\alpha 1$ and $\text{K}\alpha 2$
2 diffraction streaks with the χ -axis adjusted so that
3 these streaks were several degrees away from the
4 vertical direction.

5

6 In order to remove the blurring of a topograph from
7 a poorly aligned or macroscopically bent sample, we
8 could of course use only the $\text{K}\alpha 1$ diffraction streak
9 to create the topograph. However, in doing this we
10 would neglect 1/3 of the available intensity i.e.
11 the intensity contained in the $\text{K}\alpha 2$ diffraction
12 streak. Furthermore, this procedure would not
13 correct the geometric distortion (slanting) of the
14 topograph which is also apparent in Fig. 12.

15

16 Addition of $\text{K}\alpha$ and $\text{K}\alpha 2$ Images

17

18 To create a topograph using all of the available
19 intensity without any blurring or geometric
20 distortions we propose the following modification to
21 the basic Tile algorithm described above.

22

23 1. Create a topograph using the basic Tile
24 algorithm with the RROI in each integrated image
25 defined so as to include only the $\text{K}\alpha 1$ diffraction
26 streak.

27

28 2. Repeat step 1 but define the RROI so as to
29 include only the $\text{K}\alpha 2$ diffraction streak.

30

1 3. Perform affine transformations on the
2 topographs created in steps 1 and 2 so as to map the
3 K_{α1} and K_{α2} images on top of one another.

4

5 4. Add the transformed K_{α1} and K_{α2} topographs
6 together.

7

8 Here, an affine transformation is a generalised name
9 for as yet unspecified translation, rotation and
10 shear image processing operations.

11

12 To determine and correct the angle α at which the
13 diffraction streaks are inclined to the vertical
14 direction we propose the following simple scheme.
15 First we define two RROI's at the top and bottom few
16 percent of an integrated image. These RROI's are
17 then projected onto the horizontal axis, that is the
18 pixel values are summed along a horizontal line in
19 the image. The x-positions of the maximum pixel
20 values (by fitting the projection to a peak function
21 to obtain sub-pixel accuracy) at the top and the
22 bottom of the image could be fitted to a linear
23 equation (straight line through the two points) to
24 determine α . This procedure would be repeated for
25 all integrated images comprising the final
26 topograph. The image is then sheared by another
27 affine transformation that corrects the value of α
28 to zero, before performing the stepwise integration.

29

30

1 Modifications2
3 Modifications may be made to the above embodiments.
45 It is possible to use X-ray optics other than
6 lobster eye optics, provided a substantially
7 parallel output is obtained. For example, parabolic
8 specular or multilayer optics could be used,
9 particularly parabolic graded multilayers, but these
10 are likely to be more expensive than lobster eye
11 optics.12
13 The aperture on either side of the optic could be
14 extended by using non-graded multilayer plates, or
15 still further by using crystal reflectors such as
16 mica.17
18 The width of 30 mm is believed to be a practical
19 limit to lobster eye optics at present. The
20 Microsource® generator can provide a total aperture
21 of 40 - 45 mm at a distance of 50 mm, and so if a
22 wider optic could be made the exposure could be
23 decreased in proportion.24
25 The use of a less sophisticated optic than that
26 described would also give a useful, though somewhat
27 poorer, performance. Even a lobster eye optic of
28 only two plates would give a gain of 2.6x and a
29 processing time for a 8" wafer of 20 - 25 mins.30
31 The use of the Microsource® X-ray generator is
32 preferred for two reasons. One is the ability to

1 place the optic very close to the X-ray source. The
2 other is that the power and source size can be
3 controlled electronically to alter the tradeoff
4 between resolution and throughput according to the
5 needs of the measurement, with no mechanical
6 alterations. The latter factor also makes it
7 possible to scan the sample at relatively low
8 resolution to detect areas with some discrepancy,
9 and then to inspect such areas in greater detail.

10

11 However, the invention is not limited to the use of
12 the Microsource® generator, and other means of
13 producing X-rays may be used.

14

15 Although described with reference to the detection
16 of slip bands in Si, the invention is useful with
17 other materials, such as defect detection in EUV
18 optical material such as CaF₂ and in SiC and III-V
19 crystals.

20

21 Other modifications and improvements may be made
22 within the scope of the invention.